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EFFECT OF IRRIGATION METHODS AND NUTRIENT MANAGEMENT PRACTICES ON PRODUCTION AND ECONOMICS OF POTATO UNDER DIFFERENT PRECEDING CROP SEQUENCES IN CENTRAL INDIA

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ABSTRACT: A field experiment was conducted at ICAR-Central Potato Research Institute-RS, Gwalior, in split-plot design: 3 irrigation methods (main plots) and 5 fertilizer doses in various crop sequences (sub-plots), with four replications. Results revealed that the highest total tuber number (604 thousand/ha) was recorded with dhaincha - potato (75% RDF NPK) which was significantly higher than all other treatments except green gram - potato (75% RDF NPK). Drip irrigation resulted in highest total tuber yield (35.8 t/ha), significantly surpassing other methods. Dhaincha - potato (75% RDF NPK) combination yielded (37.5 t/ha) highest, significantly outperforming others except fallow - potato (50% RDF NPK/ha + 15 t FYM) sequence. Drip irrigation x fallow - potato (50% RDF NPK/ha + 15 t FYM) combination recorded the highest total tuber yield at 40.3 t/ha. Drip irrigation resulted in water-use efficiency of 137 kg/ha-mm and harvest index of 72%, significantly surpassing other methods. Fallow – potato {FYM 7.5 t/ha + crop residue 7.5 t/ha + biofertilizers (*Azotobacter* and PSB)} sequence recorded highest harvest index 73%, significantly surpassing other treatments. Drip irrigation resulted in highest WUE (137 kg/ha-mm), significantly surpassing other methods. Combination of drip irrigation x fallow – potato (FYM 7.5 t/ha + 50% RDF NPK) sequence recorded highest WUE (155 kg tuber/ha-mm), significantly outperforming other treatments. Dhaincha – potato (75% RDF NPK) sequence resulted in the highest **nitrogen content (216 kg/ha),** significantly surpassing others**. Dhaincha - potato (75% RDF NPK) sequence significantly out performed in tuber nitrogen uptake (77 kg/ha) to other sequences. Combination of drip irrigation x dhaincha - potato (75% RDF NPK) sequence recorded highest N uptake (83 kg/ha). Benefit : cost was highest with drip irrigation (3.1) among irrigation methods and it was highest with dhaincha - potato (75% RDF NPK) sequence (2.99) among crop sequences.**

KEYWORDS: Irrigation methods, crop sequence, nutrient management, water use efficiency, nutrient uptake

INTRODUCTION

Potato (*Solanum tuberosum* L.) is a principal food crop, and an essential source of nutrients for human populations. The annual world production of potato tubers, obtained from the cultivated area of 19.3 M ha during 2019, was around 380 million tons (FAOSTAT, 2023). Potato is ranked as the fourth crop after wheat, rice, and maize, among other crops according to the total production, and is the number one among non-grain food commodity.

The excessive inputs in agricultural systems that can achieve high productivity and quality of crops to feed a growing population are considered to be some of the most troublesome agricultural practices for environmental resources (Ekin, 2019; El Mokh, 2015; Badr *et al*., 2010). Thus, increasing food crop cultivation requires the rationalization of the inputs such as water and fertilizer applications. Additionally, due to the expense of water and its limited supply, it is important to provide better irrigation management that

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can increase its effective and efficient use to save water. Drip irrigation offers many agronomic and water conservation benefits for irrigated agriculture, such as the improved efficiency of plant nutrition. A positive relationship exists between the total applied water and tuber yield, particularly under drip irrigation (Badr *et al.,* 2010). Potatoes have a shallow root system, with 85% growing within the upper 40 cm of soil (in some cases, it may extend to 100 cm or more (Wang *et al.,* 2006). Water stress, as well as excessive water, can decrease potato yield: The former decreases plant growth and the later hinders normal plant physiological processes, since different growth stages of potato plants are sensitive to inadequate irrigation (Yuan *et al.,* 2003).

Potato yield and fertilizer applications are significantly correlated, and suitable fertilizers can significantly improve quality and yield (Šrek *et al*., 2010). Potato crops require high rates of fertilizers, particularly those containing Nitrogen (N) and Potassium (K); the requirement for N is approximately twice that of K (Bélanger, 2002).

Among the different environmental factors, water supply and its management and nitrogen fertilization are considered to be the two major limiting factors affecting potatoes' yield and quality. Water deficiency causes physiological disorder of potato and a decrease in dry matter and tuber starch content (Carli *et al*., 2014). Potato is a nitrogen-intensive plant with low nitrogen uptake efficiency (Gitari *et al*., 2018). Potato planting under over-fertilization conditions in pursuit of high yield has a high potential for N loss. The high nitrate nitrogen content in the potato root zone caused by excessive fertilization is the main problem faced by farmers (Abdo *et al*., 2020). The increase in nitrate accumulation in potato tubers caused by excessive application of nitrogen fertilizer will cause many diseases to humans and threaten the health of the whole society. Excessive nitrogen and potassium application and excessive soil nutrient levels may reduce tuber yield and quality. A balanced application of nitrogen is required to obtain adequate biomass yield, which leads to a stable yield and the production of good quality tubers. Appropriate soil moisture can promote potatoes' absorption and utilization of soil nutrients. Modern production practices include optimizing nitrogen and water use to optimize crop production and minimize the risk of leaching nitrogen into groundwater (Badr *et al.*, 2012). In the present day context, the effective and economical utilization of water and fertilizers is essential to reduce the cost of cultivation. It can best be achieved through the use of improved irrigation techniques, *viz* drip and sprinkler and supplying balanced and adequate doses of fertilizers. Drip and sprinkler irrigation can increase the yield up to 20–40% and save water up to 39% in potato crop. The response of applied fertilizers is also expected to vary with different irrigation methods as the water application frequency is different in sprinkler, drip and conventional furrow irrigation systems. Therefore, the present studies were conducted to evaluate variable nutrient options in combination with varying methods of irrigation to assess the economic feasibility of these techniques.

MATERIALS AND METHODS

The experiment was conducted at Research Farm of ICAR-Central Potato Research Institute-RS, Gwalior (MP) which is situated at $26^0$16'32"N$78^0$13'13"E at an elevation of 222.27m as per GPS location. Gwalior has a subtropical climate, reaching extreme highs of 48°C in summer and lows of 4.0°C in winter. Annual rainfall ranges from 750 to 800 mm, mainly between end-June and end-September, with occasional winter showers. Farm soil: 42.04% sand, 30.66% silt, 27.12% clay (silty clay loam) with Granular structure, soil bulk

density 1.29 g/m^3, particle density 2.61 g/m^3. Soil pH is 6.81, OC 0.45%, available N 190 kg, P 20.2 kg, and available K 395 kg/ha. Total rainfall received during the crop growth period was 49.4 mm. The average maximum and minimum temperature during crop growth period was 36 °C and 10 °C, respectively. The relative humidity ranged from 29.7% to 97.8%.

The gross plot size measured 3.0 m x 5.4 m, while the net plot size was 1.8 m x 5.0 m. Employing a split-plot design, the experiment included three main plot treatments (drip irrigation, sprinkler irrigation, and furrow irrigation) and five sub-plot treatments replicated four times. Main plot treatments focused on irrigation methods, while sub-plot treatments involved fertilizer doses: i) control, ii) 100% RDF N, P_2O_5, K_2O @ 180:80:120 kg/ha, iii) 75% RDF N, P_2O_5, K_2O @ 135:60:90 kg/ha, iv) 50% RDF N, P_2O_5, K_2O @ 90:40:60 kg/ha + 15 t FYM/ha, v) Compost + FYM @ 7.5 (t/ha each) + Bio fertilizer. Sprinkler irrigation was scheduled at IW/CPE = 1.2 when CPE reached 3.0 cm. The variety used was the Kufri Jyoti, with spacing set at 60 cm x 20 cm in the ridge furrow system and 120 cm wide raised beds. Two potato rows were planted at a 40 cm row distance under drip and sprinkler methods, while intra-row spacing in micro-irrigations was also maintained at 20 cm.

Potato was planted during first week of November in both 2020 and 2021 and harvested during second week of February, 2021 and 2022. Well sprouted seed tubers were planted manually. Irrigations were applied as per schedule through drip and sprinklers and at 15 days interval in ridge furrow systems. At planting, 1/3rd doses of fertilizers in drip and sprinkler systems and half dose N and full doses of phosphorus and potassium were applied at planting as basal dose. Remaining 2/3rd dose of fertilizers were applied in 8 equal splits twice weekly after tuber emergence in micro irrigated treatments. Remaining half dose of nitrogen in ridge – furrow system was applied at hoeing and earthing up at 26 days after planting. Different doses of fertilizers, manures and crop residue based compost along with bio fertilizers were applied as per treatment. Well decomposed organic manure *viz.* FYM along with residue based compost were applied three days before planting. Half dose of nitrogen and full doses of phosphorus and potassium were applied through urea, dia-ammonium phosphate (DAP) and muriate of potash (MOP), respectively, as basal dose at the time of planting. Weed management was done using Metribuzin which was applied @ 500 g a.i. /ha as a pre-emergence herbicide (one day after planting). Plant protection measures include spraying Imidacloprid @ 4ml/10 litre and Dithane M45@ 2 kg /ha during both the years. Haulm uprooting was done during 1st week of February and harvesting was done in 2nd week of February during both the years. The first irrigation was given immediately after planting since planting was done under dry soil condition. Subsequent irrigations were given at about 2-3 days interval using drip and sprinkler irrigation and 12-15 days interval using ridge - furrow irrigation method, as per crop requirement. After uprooting haulms, fresh plant samples (250 g haulm from each plot) were sun dried and oven drying at 62^{o} C until constant weight was achieved. After harvesting, 100 g tubers were randomly sampled from each plot. Sampled tubers were sliced for drying. Sliced tubers were sun dried and then oven dried at 62^{0}C until constant weight was achieved. Oven dried samples were weighed. Based on oven dried haulm and tuber weight, total haulm and tuber dry weight were worked out in t/ha. The harvest index was calculated by dividing the economic yield (total tuber yield) with total biological yield per net plot and then expressed as per cent.

$$\text{Harvest index (\%)} = \frac{\text{Economic yield per plot}}{\text{Biological yield per plot}} \times 100$$

$$\text{Tuber dry matter content (\%)} = \frac{\text{Dry weight of tuber}}{\text{Fresh weight of tuber}} \times 100$$

A total of 252, 270 and 360 mm water was applied in drip, sprinkler and ridge-furrow irrigated potato, respectively including 49.4 mm winter rains. Cost of irrigation and nutrient management was calculated by taking into account all items as per prevailing market rates. Both costs including common cost was added to get the total cost of cultivation of each treatment. Tuber yield was multiplied with market sale rate to get gross return. For getting net return of each treatment, cost of cultivation was subtracted by gross return with respective treatments. B : C ratio was worked out dividing gross return with cost of cultivation.

At the end of experiment, soil samples were drawn from each plot to access the nutrient status under different treatments. The yield of tubers/plot was recorded at the end of the experiment , graded in <25g, 26-50g, 51-75g, >76g and total (all) grades and expressed into metric tonnes/ha. The results obtained were subjected to statistical analysis. At the end of the experiment, total amount of water applied was calculated for each irrigation treatment and the water use efficiency (kg/ha-mm) was calculated as per the formula:

$$\text{Water-use efficiency (kg/ha-mm)} = \frac{\text{Total yield of tubers (kg/ha)}}{\text{Total water applied (mm)}}$$

RESULTS AND DISCUSSION

Growth attributes: Highest emergence was recorded under drip irrigation (94%) which was significantly higher than ridge – furrow irrigation system (92.4%). Emergence under sprinkler system was statistically similar with drip irrigation system. Among nutrient management practices, dhaincha (green manure) – potato with 75% RDF NPK recorded highest emergence count (94.6%) which was significantly higher than Fallow – potato (FYM7.5 t/ha + Crop residue 7.5 t/ha + biofertilizers –*Azotobacter* and PSB) but statistically similar with other nutrient management treatments. Significantly higher emergence count (97%) was recorded under drip irrigation x green gram – potato (75% RDF NPK) interaction. Highest plant height was recorded under drip irrigation system (66.5 cm) which was significantly higher than ridge – furrow irrigation system (62.8 cm). Plant height under sprinkler system was statistically same with drip irrigation system. Among nutrient management practices, dhaincha (green manure) – potato with 75% RDF NPK recorded the highest plant height (67.9 cm), significantly higher than all other nutrient management treatments. Significantly higher plant height (71.3 cm) was recorded under drip irrigation x dhaincha green manure – potato (75% RDF NPK) interaction. Number of stem/plant was statistically same under all irrigation treatments. Nutrient management practices did not significantly affect the number of stem/plant. Similarly, interaction of irrigation method and nutrient management practices did not significantly affect the number of stem/plant. Highest number of compound leaves/plant was recorded with drip irrigation (63.0) which was significantly higher than ridge – furrow irrigation but statistically same with sprinkler irrigation. Number of compound leaves / plant was statistically same under all nutrient management practices (Table 1). Significantly higher compound leaves/plant (72.1) was recorded under drip irrigation x dhaincha green manure – potato (75% RDF NPK) interaction. Badr *et al.* (2012) also observed appropriate soil moisture can promote the absorption and utilization of soil nutrients by potatoes.

Table 1. Effect of irrigation methods and nutrient management practices on growth and yield attributes of potato (two years mean data).

Treatments	Growth attributes				Number of tubers ('000/ha)					
	Plant Emergence (%)	Plant height (cm)	Stem/ plant	Compound leaves/ plant	<25g	25-50g	51-75g	>76g	Total	Crack tuber (%)
Irrigation methods (A)										
Drip irrigation	94.0	66.5	4.8	63.0	183	119	92	181	575	6.6
Sprinkler	92.9	66.1	4.6	61.1	178	124	92	158	552	4.9
Ridge-furrow	92.4	62.8	4.5	56.0	181	124	95	172	572	4.6
SEm+	0.4	0.7	0.1	1.2	6.3	3.4	3.1	1.8	11.2	0.6
CD (P=0.05)	1.3	2.6	NS	4.2	NS	NS	NS	6.2	NS	NS
Nutrient management /previous crop (B)										
Fallow - potato (100% RDF NPK)	93.5	64.6	4.6	58.1	173	123	91	163	550	5.7
Green gram - potato (75% RDF NPK)	93.8	64.7	4.7	60.9	200	125	93	169	587	4.9
Dhaincha - potato (75%RDF NPK)	94.6	67.9	4.9	62.1	189	120	104	191	604	6.0
Fallow – potato (FYM15 t/ha + 50% RDF NPK)	94.2	65.8	4.7	61.7	167	123	95	184	569	5.0
Fallow – potato {FYM 7.5 t/ha + crop residue 7.5 t/ha + biofertilizers (*Azotobacter* and PSB)}	89.3	62.8	4.4	57.3	176	121	82	144	523	5.0
SEm+	0.9	0.7	0.2	1.9	5.7	4.9	2.7	5.1	9.2	1.0
CD (P=0.05)	2.5	2.0	NS	NS	16.5	NS	7.9	14.5	26.4	NS
Interaction										
Factor(B) at same level of A										
SEm+	0.8	1.7	0.3	2.7	14.0	7.6	7.0	3.9	25.1	1.3
CD (P=0.05)	4.4	3.7	NS	9.7	30.8	NS	NS	25.5	NS	NS
Factor(A) at same level of B										
SEm+	1.4	1.3	0.3	3.2	10.9	8.3	5.3	8.0	18.1	1.6
CD (P=0.05)	4.1	4.1	NS	9.4	33.6	NS	NS	23.4	NS	NS

Number of tubers

Effect of irrigation methods

Irrigation methods showed non-significant effect on <25g, 26-50g, 51-75g and total tubers which ranged from 178 to 183, 119 to 124, 92 to 95, and 552 to 574 thousand/ ha, respectively. Highest number of >76g tubers was recorded with Drip irrigation (181 thousand/ha) which was significantly higher than other two irrigation methods (Table 1).

Effect of nutrient sources and interaction of nutrients and irrigation

Highest number of <25g tubers (200 thousand/ha) was recorded with greengram-potato which was significantly higher than all other treatments except dhaincha-potato (75% RDF). Interaction of drip irrigation methods x green gram – potato (75% RDF NPK/ha) nutrient application recorded highest number of <25g tubers. Number of 25-50g tubers/ha was statistically same under different nutrient management practices.

Similarly method of irrigation x nutrient management practices did not significantly affect 25-50g tubers. Highest number of 51-75g tubers (104 thousand/ha) was recorded with dhaincha-potato (75% RDF NPK/ha) which was significantly higher than all other treatments. Interaction of irrigation x nutrient management method did not show any significant effect on number of 51-75g tubers. Drip irrigation method recorded highest number of >76g tubers (181 thousand/ ha) which was significantly higher than all other irrigation methods. Number of >76g tubers differed significantly due to nutrient management practices. Highest number of >76g tubers(191 thousand/ha) was recorded with dhainch-potato (75% RDF NPK/ha) which was significantly higher than all other treatments except fallow-potato (50% RDF + FYM@15 t/ha). Interaction of drip irrigation methods x dhainch-potato (75% RDF NPK/ ha) nutrient application recorded highest number (210 thousand/ha) of >76g tubers. Highest total number (604 thousand/ha) was recorded with dhaincha - potato (75% RDF NPK/ha) which was significantly higher than all other treatments except green gram - potato (75% RDF NPK/ha). Interaction of irrigation x nutrient management method did not significantly affect the total number of tubers (Table 1). This might be due to the beneficial residual effect of kharif dhaincha as a green manure crop by fixing atmospheric nitrogen through biological means and which may be available to mineralization of plant residues, thereby increasing the growth and yield of succeeding crop. The observations are in agreement with Carter *et al.* (2009).

Grade wise yield

Effect of irrigation methods

The grade wise yield of tubers (t/ha) at harvest showed non-significant effect under irrigation methods on 25-50g. Highest tuber yield (2.6 t/ha) of <25g tubers was recorded with sprinkler irrigation which was significantly higher than other two irrigation methods. Highest yield of 51-75g tuber (6.4 t/ha) was recorded with drip irrigation which was significantly higher than all other treatments. Similarly, highest yield of >76g tuber (22.5 t/ha) was recorded with drip irrigation which was significantly higher than all other irrigation treatments. The highest total tuber yield (35.8 t/ha) was recorded with drip irrigation, significantly higher than all other treatments.

Effect of nutrient sources and interaction of nutrients and irrigation

The grade wise yield of 25-50g tubers (t/ ha) at harvest showed non-significant effect under different nutrient management practices and irrigation methods x nutrient management interaction. Highest tuber yield (2.9 t/ha) of <25g tubers was recorded with green gram-potato (75% RDF NPK) which was significantly higher than all other treatments. Interaction of Sprinkler irrigation method x green gram-potato (75% RDF NPK) nutrient management recorded highest tubers yield (3.1 t/ha). Highest tuber yield (6.9 t/ha) was recorded with dhaincha - potato (75% RDF NPK/ha) under 51-75g tubers which was significantly higher than all other treatments. Highest tuber yield (7.5 t/ha) was recorded in Drip irrigation method x fallow- potato (15 t FYM + 50% RDF NPK/ha) nutrient management practices. Similarly, highest >76g tuber yield (23.9 t/ ha) was recorded with dhaincha - potato (75% RDF NPK/ha) which was significantly higher than all other treatments. Highest >76g tuber yield (25.9 t/ha) was recorded in Drip irrigation method x dhaincha - potato (75% RDF NPK/ha) nutrient management. Highest total tuber yield (37.5 t/ha) was recorded with dhaincha - potato (75% RDF NPK) which was

significantly higher than all other treatments except fallow - potato (15 t FYM + 50% RDF NPK/ha). Highest total tuber yield (40.3 t/ha) was recorded in Drip irrigation method x fallow-potato (15 t FYM + 50% RDF NPK/ha) nutrient management. A reduced nutrient supply leads stomatal closure, thus indirectly impairing photosynthesis. The observations are in agreement with those recorded by Carter *et al.* (2009).

Tuber cracking

Effect of irrigation methods

The Number of crack tubers at harvest showed non-significant effect under irrigation methods. Maximum number of crack tuber (6.6%) was recorded with drip irrigation and minimum number of crack tuber (4.6%) was recorded with furrow irrigation. The Yield of crack tubers (t/ha) showed non-significant effect under irrigation methods. Maximum Yield of crack tubers (11.9 t/ha) was recorded with Drip irrigation and minimum yield of crack tubers (9.0 t/ha) was recorded with ridge-furrow irrigation.

Effect of nutrient sources and interaction of nutrients and irrigation

The Number of crack tubers at harvest showed non-significant effect with respect to nutrient sources. Number of maximum crack tuber (6.0%) under dhaincha – potato (75% RDF NPK/ha) sequence and minimum number of crack tuber (5.0%) under fallow – potato FYM 7.5 t/ha + crop residue 7.5 t/ha + biofertilizers – (*Azotobacter* and PSB) sequence. The yield of crack tubers (t/ha) showed significant effect on nutrient sources. Maximum yield of crack tubers (12.9%) was recorded under dhaincha - potato (75% RDF NPK/ha) sequence which was significantly higher than fallow - potato FYM 7.5 t/ha + crop residue 7.5 t/ha + biofertilizers – (*Azotobacter* and PSB) (5.4%) but statistically same with other treatments. Interaction of Drip irrigation method x fallow - potato (100% RDF NPK/ha nutrient management) recorded highest value 17.8%.

Fresh and dry haulm yield, dry tuber yield and biological yield on dry weight basis (t/ha)

Effect of irrigation methods

It was observed that differences in fresh and dry haulm yield, dry tuber yield and biological yield on dry weight basis (t/ha) at harvest were significant under different irrigation methods. Maximum fresh haulm yield (25.6 t/ha) was recorded under drip irrigation, which was significantly higher than that of sprinkler and ridge-furrow irrigation methods. Maximum dry haulm yield (3.3 t/ha) was recorded under drip irrigation which was significantly higher than sprinkler (3.0 t/ha) and ridge-furrow irrigation (2.9 t/ha). Maximum biological yield (10.3 t/ha) on dry weight basis was recorded under drip irrigation which was significantly higher than other two irrigation methods. These findings are accordance with Pawar *et al.* (2002).

Effect of nutrient sources and interaction of nutrients and irrigation

Each plant passes through the vegetative as well as reproductive phases of growth to complete its life cycle. Yield can be considered the final expression of plants' physiological and metabolic activities and is governed by various factors. These yield-attributing factors have direct bearing on plant productivity and for increasing the yield that means the yield attributing parameter play an important role. The fresh and dry haulm yield (t/ha) differed significantly with respect to nutrient sources (Table 2). The maximum fresh haulm yield (26.6 t/ha) was recorded under fallow - potato (50% RDF NPK/ha + 15 t/ha FYM) sequence which was significantly higher than

Table 2. Effect of irrigation methods and nutrient management practices on yield and fresh and dry haulm yield and harvest index of potato (two years mean data).

Treatments	Yield of tubers (t/ha)					Crack tuber yield (%)	Haulm yield (t/ha)		Dry tuber yield (t/ha)	Biological yield (t/ha)
	<25g	25-50g	51-75g	>76g	Total		Fresh	Dry		
Irrigation methods (A)										
Drip irrigation	2.4	4.5	6.4	22.5	35.8	11.9	25.6	3.3	7.4	10.7
Sprinkler	2.6	4.2	5.6	21.3	33.7	9.3	23.2	3.0	6.5	9.5
Ridge-furrow	2.3	4.3	5.6	18.6	30.8	9.0	22.7	2.9	5.6	8.5
SEm+	0.0	0.1	0.2	0.3	0.2	0.8	0.4	0.0	0.0	0.1
CD (P=0.05)	0.1	NS	0.6	1.1	0.8	NS	1.3	0.2	0.2	0.3
Nutrient management /previous crop (B)										
Fallow - potato (100% RDF NPK)	2.2	4.4	5.1	19.4	31.1	11.4	21.7	2.9	5.6	8.5
Green gram - potato (75% RDF NPK)	2.9	4.5	5.8	20.5	33.7	9.7	25.9	3.3	6.4	9.7
Dhaincha - potato (75%RDF NPK)	2.5	4.2	6.9	23.9	37.5	12.9	25.5	3.2	7.3	10.5
Fallow – potato (FYM15 t/ha + 50% RDF NPK)	2.3	4.3	6.2	23.2	36.0	11.0	26.6	3.3	6.6	9.9
Fallow – potato {FYM 7.5 t/ha + crop residue 7.5 t/ha + biofertilizers (*Azotobacter* and PSB)}	2.3	4.3	5.4	17.1	29.1	5.4	19.3	2.4	6.6	9.0
SEm+	0.1	0.2	0.2	0.5	0.5	1.2	0.5	0.1	0.1	0.1
CD (P=0.05)	0.1	NS	0.5	1.3	1.5	3.5	1.3	0.2	0.3	0.3
Interaction										
Factor(B) at same level of A										
SEm+	0.1	0.3	0.4	0.7	0.5	1.9	0.9	0.1	0.1	0.2
CD (P=0.05)	0.3	NS	0.8	2.3	2.6	6.3	2.4	0.3	0.5	0.6
Factor(A) at same level of B										
SEm+	0.1	0.3	0.3	0.8	0.8	2.1	0.8	0.1	0.2	0.2
CD (P=0.05)	0.2	NS	0.9	2.3	2.4	6.2	2.4	0.3	0.5	0.6

fallow - potato (100% RDF NPK/ha) and fallow-potato FYM 7.5 t/ha + crop residue 7.5 t/ha + biofertilizers – (*Azotobacter* and PSB). Interaction of Drip irrigation method x fallow - potato (50% RDF NPK/ha + 15 t/ha FYM) nutrient management recorded highest value (29.6 t/ha). The maximum dry haulm yield (3.3 t/ha) was recorded under fallow - potato (50% RDF NPK/ha + 15 t FYM/ha) sequence which was significantly higher than fallow-potato 100% RDF NPK/ha and fallow-potato FYM 7.5 t/ha + crop residue 7.5 t/ha + biofertilizers – (*Azotobacter* and PSB). Interaction of Drip irrigation method x fallow - potato (75% RDF NPK/ha + 15 t FYM/ha) nutrient management recorded highest value (3.7 t/ha).

The maximum dry tuber yield (7.3 t/ha) was recorded under dhaincha - potato (75% RDF NPK/ha) sequence which was significantly higher than all other treatments. Interaction of Drip irrigation method x FYM 7.5 t/ha + crop residue 7.5 t/ha + biofertilizers – (*Azotobacter* and PSB nutrient management recorded highest value 8.5 t/ha. The maximum biological yield (10.5 t/ha) on dry weight basis was recorded under dhaincha - potato (75% RDF NPK/ha) sequence, significantly higher than all

other treatments. Interaction of Drip irrigation method x dhaincha - potato (75% RDF NPK/ ha) nutrient management recorded highest value11.0 t/ha. This might be because of beneficial residual effect of kharif dhaincha as a green manuring crop by fixing atmospheric nitrogen through biological means and which may be available to mineralization of plant residues thereby increases the growth and yield of succeeding crop. The dhaincha – potato cropping sequence improved the soil health in respect of physical, chemical and biological properties which creates favorable condition for growth and development of crops and ultimately helps to increase the yield of potato crop. These results conform with the findings of Mohammed *et al.* (2016).

Harvest index (%)

Effect of irrigation methods

It was observed that differences in harvest index (%) was significant under different irrigation methods. Highest harvest index (72%) was recorded with drip irrigation which was significantly higher than other two irrigation methods. The present results are in conformity with the findings of Mohammed *et al.* (2016).

Effect of nutrient sources and interaction of nutrients and irrigation

The harvest index differed significantly with respect to nutrient sources. The maximum harvest index (72 %) was recorded under fallow – potato sequence with FYM 7.5 t/ha + crop residue 7.5 t/ha + biofertilizers (*Azotobacter* and PSB) which was significantly higher than all other treatments. Interaction of Drip irrigation method x fallow-potato FYM 7.5 t/ha + crop residue 7.5 t/ha + biofertilizers – (*Azotobacter* and PSB) sequence nutrient management recorded highest value 78.4%. Similar results were recorded by Waqas *et al.* (2021).

Water-use efficiency

Effect of irrigation methods

Water being a scarce input, its efficient use in agriculture is the serious concern for the country. Maximization of crop production per unit of water used had to be opted by using modern irrigation methods in agriculture. Looking to the performance of different irrigation methods on water use efficiency (Table 3), it was observed that differences in Water-use efficiency(WUE) (kg/ha-mm) was significant under different irrigation methods. Maximum Water-use efficiency (137 kg/ha-mm) was recorded under drip irrigation which was significantly higher than sprinkler and ridge-furrow irrigations (107 kg/ha-mm). This might be due to maintaining proper moisture and nutrient availability in rootzone through out growth period as per crop need which resulted in higher yield with lesser applied water. These results are in accordance with Pawar *et al.*, (2002) and Yuan *et al.*, (2003).

Effect of nutrient sources and interaction of nutrients and irrigation

The water-use efficiency differed significantly with respect to nutrient sources. Maximum water-use efficiency (130 kg/ha-mm) was recorded under fallow - potato (50% RDF NPK + 15 t/ha FYM) sequence which was significantly higher than all other treatments. Interaction of Drip irrigation method x fallow – potato (FYM 7.5 t/ha + 50% RDF NPK) sequence recorded highest value 155 kg tuber/ha-mm.

Soil analysis

pH and OC of soil after potato harvest

Effect of irrigation methods

The chemical properties of soil viz., pH and organic carbon were determined before experiment and after experiment of crop under different irrigation methods. Table

Table 3. Effect of irrigation methods and nutrient management practices on nutrient uptake, nutrient status of soil and WUE (two years mean data)

Treatments	Tuber nutrient uptake (kg/ha)			Nutrient status of soil					Harvest index (%)	WUE (kg/ha-mm)
	N	P	K	pH	OC (%)	N (kg/ha)	P (kg/ha)	K (kg/ha)		
Irrigation methods (A)										
Drip irrigation	75	15	136	6.9	0.47	216	20	424	72	137
Sprinkler	67	16	124	6.9	0.46	207	20	423	69	107
Ridge-furrow	60	13	104	6.9	0.46	200	20	422	63	107
SEm+	3.5	0.8	1.1	0.0	0.01	1.38	0.0	0.8	0.3	0.6
CD (P=0.05)	NS	NS	4.0	NS	NS	4.02	NS	NS	1.1	2.3
Nutrient management /previous crop (B)										
Fallow - potato (100% RDF NPK)	56	13	103	6.9	0.44	204	19	409	66	105
Green gram - potato (75% RDF NPK)	68	14	119	6.9	0.47	208	20	430	66	120
Dhaincha - potato (75%RDF NPK)	77	18	142	6.8	0.49	216	21	446	69	122
Fallow – potato (FYM15 t/ha + 50% RDF NPK)	69	16	124	6.9	0.46	211	21	425	66	130
Fallow – potato {FYM 7.5 t/ha + crop residue 7.5 t/ha + biofertilizers (*Azotobacter* and PSB)}	66	13	120	6.9	0.45	200	19	405	72	109
SEm+	1.9	0.6	2.2	0.0	0.01	1.97	0.1	2.6	0.5	1.6
CD (P=0.05)	5.4	1.8	6.5	NS	0.03	6.14	0.2	7.6	1.6	4.7
Interaction										
A x B										
SEm+	7.7	1.7	2.6	0.1	0.01		0.1	1.7	0.7	1.4
CD (P=0.05)	10.5	NS	11.4	NS	NS	NS	NS	NS	2.8	8.3
BxA										
SEm+	4.5	1.3	3.7	0.1	0.02		0.1	4.2	0.9	2.6
CD (P=0.05)	14.7	NS	10.8	NS	NS	NS	NS	NS	2.7	7.6

3 presented a slight improvement, but no remarkable change was found in chemical properties under different irrigation methods. It was observed that differences in pH and OC of soil after potato harvest were non-significant under different irrigation methods.

Effect of nutrient sources and interaction of nutrients and irrigation

The pH, after potato harvest differed non-significantly with respect to nutrient sources. (Table 3) and OC of soil showed slight variation which was significant. Highest OC (0.49%) was recorded with dhaincha - potato which was significantly higher than fallow-potato (100% RDF NPK) and fallow-potato without inorganic suppy of nutrients. Interaction of irrigation method x nutrient management was found to be non-significant.

Available N, P, and K (kg/ha) of soil after potato harvest.

Effect of irrigation methods

It was observed that differences in available nitrogen of soil after potato harvest were significant under different irrigation methods. However, phosphorus and potassium were non- significant under different irrigation methods (Table 3). The

maximum nitrogen of soil (216 kg/ha) was recorded under drip irrigation which was significantly higher than other two methods.

Effect of nutrient sources and interaction of nutrients and irrigation

The available nitrogen, phosphorus and potassium of soil after potato harvest differed significantly with respect to nutrient sources. The maximum nitrogen (216 kg/ha) was recorded under dhaincha – potato sequence with 75% RDF NPK which was significantly higher than all other treatments except fallow-potato (50%RDF NPK + 15 t FYM/ ha). Results are in conformity with Wang *et al.* (2020). Interaction of irrigation method x nutrient management was found to be non-significant. The maximum phosphorus (21 kg/ha) was recorded under dhaincha - potato sequence with 75% RDF NPK which was significantly higher than all other treatments except fallow-potato (50%RDF NPK + 15 t FYM/ha). Interaction of irrigation method x nutrient management was found to be non-significant for available P. Similar trend was also recorded for potassium wherein highest available K content (446 kg/ha) was recorded with dhaincha - potato sequence with 75% RDF NPK which was significantly higher than all other treatments except fallow-potato (50%RDF NPK + 15 t FYM/ha). Interaction of irrigation method x nutrient management was found to be non-significant for available K. This clearly reveals that, dhaincha as green manuring crop in rotation helps to maintain the organic matter and increases the availability of nutrients to potato crop. The observations are in agreement with Xing *et al.* (2022).

Uptake of N, P, and K by tuber

Effect of irrigation methods

It was observed that differences in uptake of potassium by tuber were significant under different irrigation methods. While tuber nitrogen and phosphorus uptakes were non-significant under different irrigation methods (Table 3). Maximum tuber potassium uptake (136 kg/ha) was recorded under drip irrigation which was significantly higher than sprinkler (124 kg/ha) and ridge furrow (104 kg/ha) irrigation.

Effect of nutrient sources and interaction of nutrients and irrigation

The uptake of nitrogen, phosphorus and potassium by tuber differed significantly with respect to nutrient sources (Table 3). Maximum tuber nitrogen uptake (77 kg/ ha) was recorded under dhaincha - potato sequence with 75% RDF NPK, significantly higher than all other treatments. Gitari *et al.* (2018) also reported that potatoes are nitrogen-intensive plants with low nitrogen uptake efficiency. The interaction of drip irrigation x dhaincha - potato (75% RDF NPK) sequence recorded the highest value of 83 kg/ha for N uptake. Maximum tuber phosphorus uptake (18 kg/ha) was recorded under dhaincha - potato sequence with 75% RDF NPK, significantly higher than all other treatments. Interaction of irrigation method x nutrient management was found to be non- significant for P uptake. Similar trend was also recorded for potassium uptake also.

Economics

The data on economics indicating cost of cultivation, gross return, net return and benefit cost ratio under different nutrient sources and irrigation methods are presented in Table 4. The cost involved in field operations common to all treatments. Highest cost of cultivation incurred in drip irrigation (₹ 149906/ha) among irrigation methods and with fallow - potato sequence (100% RDF NPK) (₹ 147306/ha). The lowest cost of cultivation (₹ 149180/ha) was recorded with ridge-furrow irrigation and with fallow – potato (FYM 7.5 t/ha + Crop residue 7.5t/ha + Biofertilizers – *Azotobacter* and PSB)

Table 4. Effect of irrigation methods and nutrient management practices on economics of potato production (two years mean data).

Treatments	Economics (₹/ha)			B:C
	Cost of cultivation	Gross return	Net return	
Irrigation methods (A)				
Drip irrigation	149906	459986	310080	3.10
Sprinkler	149180	409234	260054	2.74
Ridge-furrow	149180	349744	200564	2.34
SEm+		2709	2708	0.02
CD (P=0.05)		9558	9551	0.07
Nutrient management /previous crop (B)				
Fallow - potato (100% RDF NPK)	147306	385524	238218	2.60
Green gram - potato (75% RDF NPK)	146580	421633	275053	2.90
Dhaincha - potato (75%RDF NPK)	146580	439205	292625	2.99
Fallow – potato (FYM15 t/ha + 50% RDF NPK)	146353	421653	275300	2.88
Fallow – potato {FYM 7.5 t/ha + crop residue 7.5 t/ha + biofertilizers (*Azotobacter* and PSB)}	141600	363592	221992	2.56
SEm+	-	6226	6226	0.04
CD (P=0.05)	-	17929	17929	0.12
Interaction				
A x B				
SEm+	-	6058	6054	0.04
CD (P=0.05)	-	31564	31564	0.22
BxA				
SEm+	-	10018	10017	0.07
CD (P=0.05)	-	29325	29323	0.20

sequence (₹ 141600/ha). Highest gross return of ₹ 459986/ha was recorded under drip irrigation and ₹ 439205/ha with dhaincha - potato sequence (75% RDF NPK). The lowest gross return ₹ 349744/ha was recorded under ridge-furrow irrigation and ₹363592/ha with fallow – potato (FYM 7.5 t/ha + crop residue 7.5 t/ha + biofertilizers – *Azotobacter* and PSB) sequence. Highest net return ₹ 310080/ha was recorded under Drip irrigation and ₹ 292625/ ha with dhaincha - potato (75% RDF NPK) sequence. The lowest net return ₹ 200564/ha was recorded under furrow irrigation and ₹ 221992/ha with fallow-potato (FYM 7.5 t/ha + crop residue 7.5 t/ha + biofertilizers *Azotobacter* and PSB). Highest benefit : cost (3.1) was recorded under drip irrigation, significantly higher than other irrigation methods. Benefit : cost was highest (2.99) with dhaincha - potato (75% RDF NPK) sequence which was significantly higher than Fallow -potato (100% RDF NPK) and Fallow – potato (FYM 7.5 t/ ha + crop residue 7.5 t/ha + biofertilizers *Azotobacter* and PSB). The lowest benefit : cost (2.34) was recorded under ridge - furrow irrigation however it was lowest with fallow – potato (FYM 7.5 t/ha + crop residue 7.5 t/ha + biofertilizers (*Azotobacter* and PSB) sequence.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest

ETHICAL STATEMENT

This article does not contain any studies with human participants or animals performed by any of the authors

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